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Zhigang Chen

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San Francisco State University
1600 Holloway Ave, San Francisco, CA
94123

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Dr. Arje Nachman-NE

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14. ABSTRACT

The primary objective of this project is to study light localization and routing in optically-induced photonic bandgap structures, and to promote education and research in optics and photonics at San Francisco State University, one of the national HBCU/MIs. We are happy to report that we made significant accomplishments on controlling light in nonlinear photonic lattices, and successfully completed this funded project. More than 30 scientific research papers have been published in top-rated refereed journals including Physical Review Letters and Optics Letters. Work from these papers have also been selected and featured in premier magazines such as *Optics & Photonics News*, and have been presented in several invited talks.

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FINAL REPORT (FEB 2009)

Zhigang Chen
San Francisco State University
biglasers@gmail.com

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Abstract:

The primary objective of this project is to study light localization and routing in optically-induced photonic bandgap structures, and to promote education and research in optics and photonics at San Francisco State University, one of the national HBCU/MIs. We are happy to report that we made significant accomplishments on controlling light in nonlinear photonic lattices, and successfully completed this funded project. More than 30 scientific research papers have been published in top-rated refereed journals including Physical Review Letters and Optics Letters. Work from these papers have also been selected and featured in premier magazines such as *Optics & Photonics News,* and have been presented in several invited talks.

Summary of Major Efforts and Accomplishments:

In the last three project years, we successfully demonstrated several phenomena related to light localization, light beam manipulation, and light signal routing in optically-induced photonic bandgap structures, including linear and nonlinear control of light in uniform optical periodic structures as well as in defects and surfaces of specially-designed photonic lattices. Specifically, we demonstrated various lattice solitons in discrete optical systems, photonic bandgap guidance in lattices with structured defects, linear and nonlinear optical surface states at the interfaces between homogeneous media and photonic lattices, and nonlinear spectrum reshaping and bandgap engineering with novel induced photonic structures. We are happy to report that we have made significant progress in this funded project. More than 30 scientific research papers have been published in top-rated refereed journals including *Physical Review Letters*, *Optics Letters* and *Optics Express.* (See attached list of publications that have acknowledged the support from AFOSR). In addition, several students have actively involved in this project, and close collaboration has been maintained with other principal investigators supported by AFOSR.

1. Controlled rotation of solitons in periodic ring photonic lattices

We have studied both theoretically and experimentally the formation of optically-induced ring photonic lattices with radial symmetry, and demonstrated rotary discrete solitons in such lattices. The controlled transition from discrete diffraction due to coupling to the center-core guidance may find application in optical limiting, while soliton rotation could be used for all-optical switching and routing in waveguide network. This part of the work has been published in *Physical Review Letters*.

2. Photonic bandgap guidance in lattices with structured defects

We have studied both theoretically and experimentally the formation of photonic lattices with defects, and demonstrated guiding light by such defects in linear region, akin to creation of "photonic crystal fibers" in bulk media. We have realized linear bandgap guidance by a low-index core in periodic square lattices and Bessel-like ring lattices. The latter configuration is more analogous to all-solid PCF with a low refractive-index core. This part of the work has been published in *Physical Review Letters* and Optics Letters.

3. Nonlinear defect modes (defect solitons)

We have studied defect solitons and their stability in one-dimensional photonic lattices with focusing saturable nonlinearity. It has been shown that defect solitons bifurcate out from every infinitesimal linear defect mode. Low-power defect solitons are linearly stable in lower bandgaps but unstable in higher bandgaps. At higher powers, defect solitons become unstable in attractive defects, but can remain stable in repulsive defects. This part of the work has been published in *Physical Review E.*

4. Novel mixed nonlinear localized modes of doubly-charged vortices.

We performed both experimental and theoretical studies of self-trapped doubly-charged vortices in 2D square lattices that are optically induced with partially coherent light. We demonstrated a host of novel phenomena such as vortex transformation, angular momentum transfer, charge flipping, and quasi-vortex solitons. This part of the work has been published in *Optics Letters* and *Optics Express* in 2006.

5. Nonlinear Tamm states as 2D surface solitons

We demonstrated the first experimental observation of two-dimensional surface solitons at the boundaries (edges or corners) of a finite optically-induced photonic lattice. Both in-phase and gap nonlinear surface self-trapped states were observed under single-site excitation conditions. These experimental results represent the first demonstration of 2D nonlinear Tamm-like surface states in any nonlinear systems. These nonlinear surface states may find applications in optical sensors and surface detection.
This part of the work has been published in *Physical Review Letters* in March, 2007, and has been featured in *Optics & Photonics News*, "Optics in 2007".

6. Nonlinear spectrum reshaping and gap-soliton-train trapping

We made the first theoretical prediction and experimental demonstration of gap soliton trains in a self-defocusing photonic lattice. Without *a priori* spectral or phase engineering, a stripe beam whose "Bloch momentum" lies in one transverse direction evolves into a gap soliton train with growing momentum also in the orthogonal direction due to nonlinear transport and spectrum reshaping. Our results suggest that a gap soliton might arise from Bloch modes even if these modes are not initially excited or only weakly excited.
This part of the work has been published in *Physical Review Letters* in May, 2007.

7. Two-dimensional defect modes in optically induced photonic lattices

In collaboration with Dr. J. Yang at University of Vermont, we have developed a new theoretical approach for systematic analysis of localized linear defect modes due to band gap guidance in two-dimensional photonic lattices with localized or nonlocalized defects. We showed for the first time that an optical vortex can propagate undistorted as a linear 2D defect mode.
This part of the work has been published in *Physical Review A* in 2007.

8. First demonstration of embedded lattice solitons

We made the first theoretical prediction and experimental demonstration of embedded lattice soliton trains in two-dimensional square photonic lattice. Such solitons arise from the X-symmetry points in the first Bloch band, which can still reside (embedded) in the first band of a 2D photonic lattice or move to the band gap between 1st and 2nd band. Contrary to the normal belief that the lattice solitons should bifurcate from the edge of the Bloch band, this demonstration also illustrates that lattice solitons can bifurcate from the non-edge (or sub-edge) high-symmetric point of the Bloch band.
This part of the work has been publication in *Physical Review Letters* in 2007.

9. Band-gap engineering and light manipulation in ionic-type photonic lattices

Recently, we have shown that a new type of photonic lattices, such as an egg-crate structure not so amenable to fabrication, can be established in nonconventionally biased (NCB) photorefractive crystals. This new setting enables the reconfiguration of desired photonic structures and Brillouin Zones (BZs) for band-gap engineering and light manipulation. Some typical examples include Band-gap closure and Bragg reflection suppression, soliton transition between different band-gaps, and interplay between normal and anomalous diffraction/refraction under identical excitation condition. This part of the work has been published in Optics Letters/Optics Express in 2008, and has been featured in *Optics & Photonics News*, "Optics in 2008".

Interactions/Collaborations:

Participation of students and postdoc researchers in the proposed research

The P.I. has actively engaged students, especially underrepresented minorities, in his research. During the past three years, the P.I. has supervised over a dozen students, and two postdoctoral researchers. Currently, there are several undergraduate and M.S. graduate students including woman and minority students working in PI's lab, with support from AFOSR and NSF.

Collaboration with other scientists

During the last couple of years, the P.I. has been in closed contact/collaboration with applied mathematician including Prof. M. J. Ablowitz at University of Colorado, Prof. J. Yang at University of Vermont, Prof. Christodoulides at University of Central Florida, and Prof. P.G. Kevrekidis at UMass/Amherst. Some of them have also been founded by AFOSR. The P.I. will continue the collaboration with other contractors and discuss with them about productive plans and future collaboration for the AFOSR projects.

Publications Acknowledged Support from AFOSR during 2006-2008:

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10. P. G. Kevrekidis, H. Susanto, and Z. Chen, "High-Order-Mode Soliton Structures in Two-Dimensional Lattices with Defocusing Nonlinearity", *Phys. Rev. E,* **74**, 066606 (2006).
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    (December special issue, "Optics in 2006").
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25. E. Evgenieva, A. Bezryadina, A. Fors, and Z. Chen, "Rotating and reversing quasi-vortex solitons in partially coherent photonic lattices", submitted to *Opt. Express.*
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28. H. Yi, C. Lou, P. Zhang, S. Liu, F. Xiao, J. Zhao, J. Xu and Z. Chen, "Observation of orientation-induced transition of in-band and in-gap solitons with hybrid nonlinearity", submitted to Opt Lett.
29. P. Zhang, C. Lou, S. Liu, F. Xiao, J. Zhao, J. Xu and Z. Chen, "Brillouin zone reconfiguration and light manipulation in egg-crate-type photonic lattices", submitted to *Phys. Rev. Lett.*
30. X Wang and Z. Chen, "Bending, splitting and routing light along defect channels", submitted to Opt. Express.

Invited Book Chapters:

1. Z. Chen, and J. Yang, "Controlling light in reconfigurable photonic lattices", Review Book Chapter, in *Nonlinear Optics and Applications*, H. Abdeldayem & D. O. Frazier, ed. p. 103-149 (Research Signpost, 2007). 978-81-308-1073-5
2. J. Yang, X. Wang, J. Wang, and Z. Chen, "Light localization by defects in optically induced photonic structures", Invited Book Chapter, in Nonlinearities in Periodic Structures and Metamaterials", C. Denz, S. Flach, and Y. Kivshar ed., (Springer, Berlin, to appear 2008).